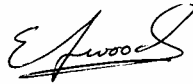**Princeton University**
Program in Environmental Engineering and Water Resources
Department of Civil and Environmental Engineering
Princeton, NJ 08544

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Land Surface Predictability Studies at GFDL

Eric F. Wood, Principal Investigator
Department of Civil Engineering and Operations Research
Tel: 609-258-4675; Fax: 609-258-2799
E-mail: efwood@princeton.edu

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LAND SURFACE PREDICTABILITY STUDIES AT GFDL

1.0 Introduction and Background

Understanding the role of the terrestrial hydrosphere-biosphere in Earth's climate system, especially the coupling of land surface hydrologic processes to atmospheric processes over a range of spatial and temporal scales, is an integral component of the World Climate Research Programme's (WCRP) Global Water and Energy Experiment (GEWEX), NOAA's GEWEX Americas Prediction Project (GAPP) and NASA's Global Water and Energy Cycle (GEWEC) initiative. The stated goals of GEWEX, are "To understand and model the influence of continental hydroclimatic processes on ... the climate system". The specific scientific issues to be addressed, as identified by the GEWEX Hydrometeorology Panel are:

- How do land areas respond to the large-scale climate system?
- How do atmosphere-land surface interactions operate and feed back onto the regional and larger scale climate system?
- How do these interactions operate over the annual cycle and what are their most critical periods in terms of feedbacks?"

To address these scientific issues within a global context, GHP, through its five Continental Scale Experiments (CSEs), has initiated a cooperative effort for a Coordinated Enhanced Observing Period (CEOP) in the 2001-2004 time period. The CEOP effort focuses on the land surface-atmospheric interactions and their impacts on regional and larger scale climate systems.

Within the U.S. programmatic area, the GAPP program objectives are (http://www.ogp.noaa.gov/mpe/gapp/gapp/index.htm) "to make monthly to seasonal predictions of the hydrological cycle and to use these improved predictions for better water resources management." To meet these objectives, there requires improvements in the land surface hydrology, and its coupling to the atmosphere, in models used for climate prediction. From these improvements, advanced studies in the predictability of land surface processes, a GAPP focus area, can be undertaken.

A goal of NOAA Geophysical Fluid Dynamics Laboratory is to develop and new climate model using enhanced land surface hydrologic parameterizations, and to carry out seasonal to inter-annual prediction studies. These studies have great potential in supporting the scientific goals of GAPP.

Achievement of the GAPP science objectives related to predictability in land surface processes, improved seasonal climate predictions, and use of predictions for water resource management requires collaboration between climate modelers and macroscale hydrologic modelers. It is occurring under this research project in which the supported post doctoral research associate, in this case Lifeng Luo, provides an effective research interface between GFDL (land modeling area) and Princeton University (i.e. my group), so as to develop the collaborative activities in climate model land hydrology and seasonal prediction studies.

2.0 Research Objectives.

The objectives of the GFDL research activities are:

1. To carry out seasonal predictability studies using initializations based on land surface states derived from observations. This addresses the GAPP objective related to Predictability in Land Surface Processes—specifically the objectives related to the effects of soil moisture and snow cover on the initialization in seasonal predictions and to better understand the seasonal cycle of snow and soil moisture.
2. To interact with GFDL climate modeling group to incorporate essential elements of the Princeton VIC land surface model into the new GFDL climate models, and to test the impact of the new land surface scheme in climate predictions.

3.0 Activities during the first year.

The funding from NOAA/OGP/Lawford for a research associate has focused on the first research objective, namely predictability and forecasting of the hydrological cycles on the seasonal-to-interannual time scales with scientists at NOAA's Geophysical Fluid Dynamics Laboratory (NOAA/GFDL). It also benefits from cooperative, synergistic research activities between Princeton University (Eric F. Wood) and the University of Washington (Dennis Lettenmaier) in the area of seasonal forecasting.

The post-doctoral research support started supporting Lifeng Luo in April 2003, and it has been progressing well. The work done at Princeton University followed two tracks: (i) predictability of seasonal climate by the GFDL model; and (ii) operational seasonal forecasts useful for applications. These two tracks are well connected, but each of them addresses the research goal from a different perspective.

3.1 Precipitation Predictability Study.
We refer to the first track (predictability of seasonal climate) as the 'scientific track' because of the basic nature of the work. The scientific track focuses on answering questions related to predictability of the hydrological cycle, such as
1) What is the predictability of precipitation at seasonal-to-interannual time scale?
2) What are the factors that contribute to the predictability?
3) Can we improve the seasonal precipitation forecast by increasing our knowledge on those contributing factors?
And as these questions relate to the GFDL climate model, and its predictability relative to other climate models such as NASA's NSIPP model.

To answer these questions, we have been using the GFDL flexible modeling system (FMS) to carry out GCM simulations. The experiments (shown in Table 1) are designed to enable us to separate the impact of different components in the climate system on precipitation variability and potential predictability. These components include ocean boundary conditions (SST) and land surface boundary conditions (land surface model). Contribution from SST can be investigated by comparing model integrations forced with observed SST time series with integrations forced with climatological SST. Contribution from land can be investigated by comparing model integrations among climatological land conditions, prescribed interannually varying land

conditions and fully interactive land conditions. The combination of these components results in 6 experiments listed below.

Table 1: Experiments performed at GFDL

	Climatological Land	*Prescribed interannual-varying Land*	*Interactive land*
Climatological SST	A	ALX	AL
Observed SST	AO	AOLX	AOL

We have performed six 22-year (1979-2000) ensemble runs for each of the experiments. This gives us 132 years (or 126 years if we omit the first year) of model outputs for each experimental setup. The Hurrell SST is used from 1979- 2000. The climatological land comes from the climatology of six AOL ensembles. The prescribed interannually-varying land condition comes from the first ensemble of the AOL experiment.

We have started analyzing the model output, with focus on the land contribution to mid-latitude precipitation variability. All the results and the progress on this can be found at http://hydrology.princeton.edu/~luo/research/SI. As one example of the results, look at figures 1 and 2 below.
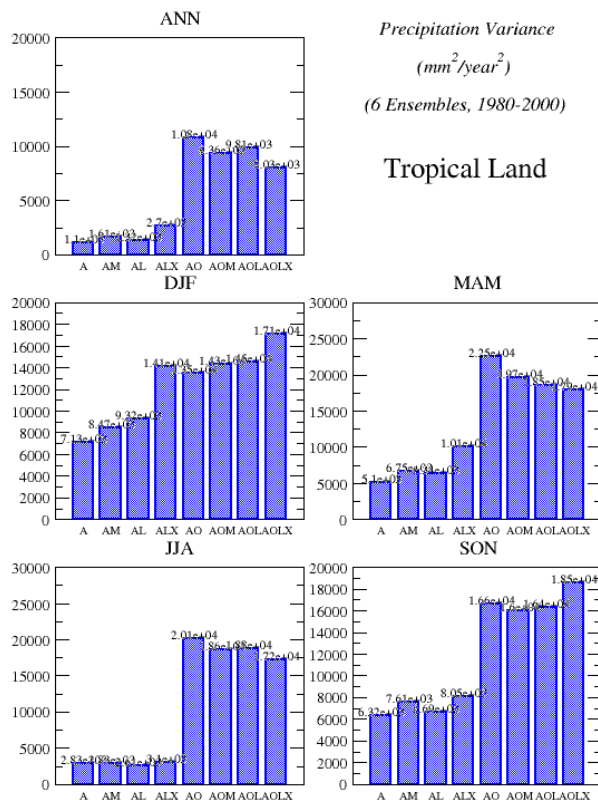
Figure 1: Precipitation variance for Tropical Land for the eight experiments, from left to right being A, AM, AL, ALX, AO, AOM, AOL, AOLX, and M means the climatology uses the Ensemble mean.
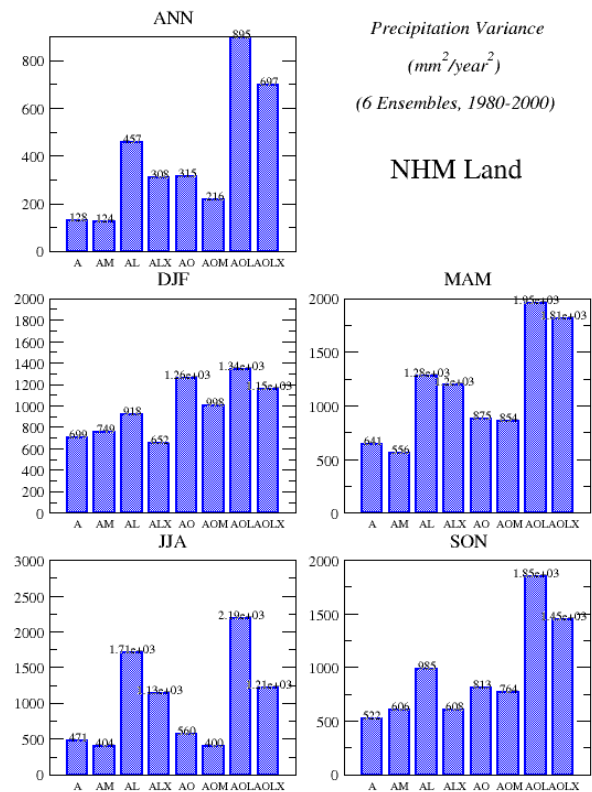
Figure 2: Precipitation variance Northern Hemisphere mid-latitude land for the eight experiments, from left to right being A, AM, AL, ALX, AO, AOM, AOL, AOLX, and M means the climatology uses the Ensemble mean.

Figure 1 shows the change in precipitation variability across the ensembles as ocean or land variability is added. For the tropics, these preliminary results demonstrate that almost all precipitation variability (in the GFDL FMS climate model) can be attributed to ocean variability. For the with the Northern Hemisphere mid-latitude land area, summertime land variability (AL and AOL experiments) contribute to the precipitation variability but for the winter season (DJF), ocean variability dominates the precipitation variability. This suggests that knowledge of ocean SST will contribute to seasonal precipitation predictability in the winter but land states (mostly soil moisture) contribute to seasonal summertime precipitation predictability.

Further analysis of the ensembles and a quantitative description of the GFDL FMS seasonal predictability will be the focus for the second year. Additionally we need to determine whether we need to compute additional ensembles and/or extend the length of each run if necessary. Then we will start to perform testing seasonal forecast/hindcast using the GFDL FMS, to augment the Global Spectral Model (GSM) work we are doing under the operational/applications track, whose progress is described below.

3.2 Seasonal Hydrology Forecast System (Operational/Application Track)
The application operational track of this project focuses on building a seasonal hydrologic forecast system using seasonal climate predictions, and testing its suitability for operational use and applications. In doing so, we also are able to investigate the predictability of streamflow and other land surface hydrologic conditions using the VIC land surface model with the current seasonal forecast released from operational centers.

We have progressed significantly in building a prototype forecast system for the Ohio River basin based on the VIC hydrological model, but it can be extended to include other land surface models. We use the seasonal forecasts from NOAA's Global Spectral Model (GSM) at NCEP and NASA Seasonal-to-Interannual Prediction Project (NSIPP) model to force VIC and a simple routing model to produce streamflow forecast for specific gauge locations within the Ohio basin. The forecast system takes the monthly mean precipitation and near surface air temperature from GSM and NSIPP and corrects them for bias. This is done using the historical probability distribution of the observations in comparison to the model's climatological distribution estimated from either the hindcast set of runs or a multi-decades AMIP-type integration. The bias correction method is described by Wood et al. (2002). The bias correction is done at the GCM grid-scale and the correction factors are downscaled to 1/8 degree at which the hydrological forecast system is running. This method efficiently reduces the bias in the GCM precipitation and air temperature both in their first and second statistical moments. The forecast system is running at a daily time step, the atmospheric forcing comes from the re-sampling and adjusting of the observations; namely the 50 year NLDAS forcing described by Maurer et al, 2002. The initial condition of the land surface system is the spin-up state using the real-time NLDAS forcing.

At present, we are able to produce 6-month streamflow forecast. These are 'issued' every month closely following the release of GSM and NSIPP seasonal forecast. The preliminary forecast product are available at: http://hydrology.princeton.edu/~luo/research/FORECAST/ Figure 3 gives an example for USGS gauge 03072500, Mononqahela River at Greensboro, PA in the Upper Ohio basin and with a basin area 4407 sq. mi. We also perform streamflow hindcasts (retrospective forecasts) each month over the Ohio basin using the GSM hindcast. These

hindcast will be the basis for the validation and evaluation of the forecast system as well as the GSM forecast accuracy. Such a forecast system enables us to resolve whether seasonal climate forecasts are skillful and whether this skill can be transferred into useful hydrological forecast at seasonal timescale.
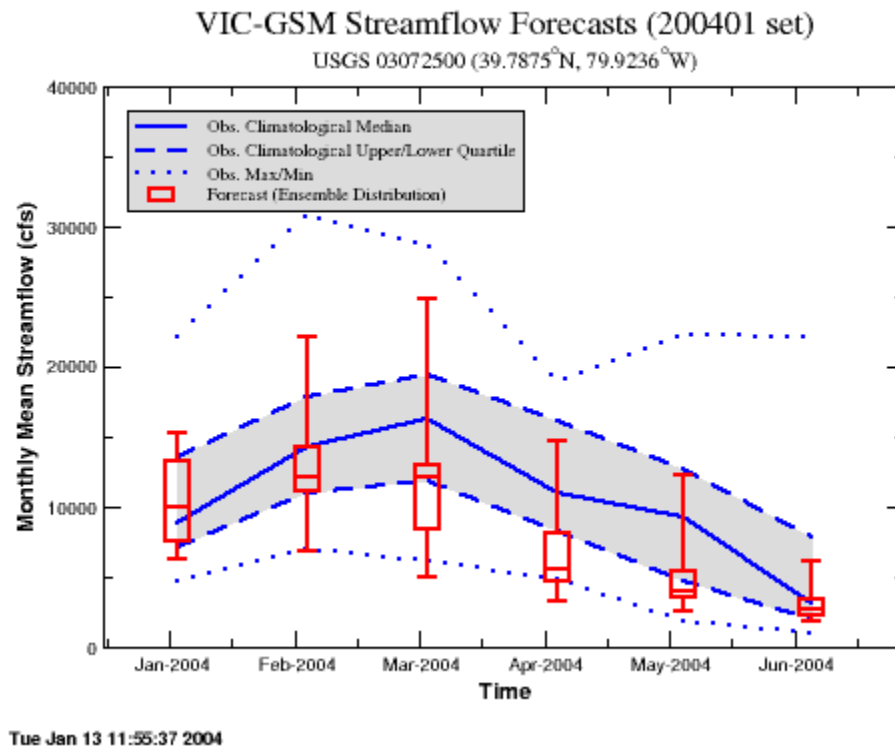
Figure 3: Six months seasonal streamflow forecast for the Mononqahela River at Greenboro, PA for the period January 2004 to June 2004 based on NCEP GSM seasonal forecasts.

Over the next year we will evaluate the streamflow forecasts in terms of its predictability and forecast accuracy over the Ohio basin. We will increase the suite of seasonal forecasts to include the NWS's Ensemble Streamflow Prediction (ESP) approach (basically resampling from the historical record and utilizing the NLDAS initial land states for the streamflow forecasts) and perhaps IRI's suite of seasonal climate model predictions. In addition, we will be analyzing and improving the forecast system, perhaps extending the products to include soil moisture.

Once we can do seasonal forecasting with the GFDL FMS climate model (i.e. the scientific track described in section 3.1), we will merger these two tracks and couple the seasonal hydrological forecast system with the GFDL seasonal predictions.

3.2 Improved land surface parameterizations.
Work is progressing on interacting with GFDL's Land Model Development Team (LMDT) utilizing support mechanisms other than the OGP post-doctoral support. The group (specifically Ming Pan, Justin Sheffield and Eric Wood) has been interacting with the Land Model Development Team (LMDT) that is structuring the new land surface hydrology parameterization for the new GFDL climate model to see what aspects of VIC can be incorporated.

The first major aspect was to incorporate the VIC sub-grid variability in runoff. The second area of interaction was improved snow, frozen ground and permafrost algorithms. A third are should be elevation banding for precipitation and snow. In addition, we have developed a land surface validation plan, and will start to work on that later this Spring.

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